

Z/A dependence of the cosmic muon-electron collision cross section

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A study has been made on the dependence of muon-electron collision cross section on Z/A of the target material at different muon energy, on the basis of our experimental results along with the results of Stoker *et al* and Das. These results show an appreciable dependence of muon-electron collision cross section on Z/A of the target material. This fact is supported by the Bhabha theory for electron energy transfer 60-160 MeV.

1. INTRODUCTION

Experiments have been performed by many physicists on the Coulombian interaction between muon and electron in different elements. The muon-electron collision cross section depends primarily on the energy transferred to the electrons, the primary muon energy and Z/A of the target material. The knock-on electron collision cross section of cosmic muons in relation to energy transfer has been reported by a number of investigators. In our previous work (De *et al* 1971) the dependence of knock-on electron cross section on primary muon energy has been studied in detail using experimental results of the various authors. It has been found that the knock-on electron cross section increases with primary muon energy up to at least 32 GeV. This fact is in accordance with Bhabha theory for energy transfer above 15 MeV.

Only few experiments (Cagliotti *et al* 1955, Lloyd & Wolfendale 1959, Viswanathan *et al* 1963) have been reported to indicate the dependence of knock-on electron cross section on Z/A of the target material. The data presented so far are inconclusive. This paper reports a study of Z/A dependence of knock-on electron cross section using the results of Stoker *et al* (1963), Das (1966), Bhattacharyya & Sen Gupta (1969) and Bhattacharyya (1973). All of these experiments have been carried out using different target elements in a counter controlled cloud chamber.

The experimental results of different authors and those calculated from the quantum electrodynamical theory of collision processes as given by Bhabha (1938) for energy transfer to electrons of at least 10 MeV have been compared.

2 EXPERIMENTS

The muon electron collision cross section data in lead and copper in the specific energy region 0.7, 1.1 and 1.6 GeV the muon have been taken from our previous report (Bhattacharyya & Sen Gupta 1969, Bhattacharyya 1973) along with the results of Stoker *et al* (1963) and Das (1966). Das in his experiments has found the mean energy of muon as 6 GeV with cloud chamber target materials of carbon, aluminium and copper. In the cloud chamber measurements of Stoker *et al* the mean muon energies have been estimated as 7 GeV with lead plates as target materials.

3 RESULTS AND DISCUSSION

The experimental cross section σ for the production of knock-on electron events by muons of incident energy E_μ is given by

$$\sigma = T/(Mtn) \quad \dots (1)$$

where T is the number of events observed during the total muon traversal of Mt g cm⁻² of any material and n is the number of atoms per gram of the target material. The experimental results of the muon electron collision cross section per g cm⁻² have been estimated from the work of different authors (Stoker *et al* 1963, Das 1966, Bhattacharyya & Sen Gupta 1969, Bhattacharyya 1973) and plotted as a function of Z/A of the target material in Figures 1 and 2. The experimental points are plotted for four target materials namely carbon, aluminium, copper and lead, corresponding to Z/A of 0.5, 0.48, 0.456 and 0.397, respectively.

The cross section per g cm⁻² of target material for the production of a collision electron in the energy band E_1 to E_2 by muons of energy E_μ as given by Bhabha (1938) from quantum electro-dynamical aspects is

$$\sigma(E_\mu, E_1-E_2) \approx \frac{2\pi r_e^2 m_e c^2 N Z}{A} \int_{E_1}^{E_2} [1 - E/E_m + \frac{1}{2}(E/E_\mu)]^2 \frac{dE}{E^2} \quad \dots (2)$$

where r_e and m_e are the classical radius and mass of the electron respectively, E is the kinetic energy of the electron, N is the Avogadro's number, Z and A are the atomic number and atomic weight of the target material, $m_e c^2$ is the muon rest energy, E_m is the maximum transferrable kinetic energy of a muon given by

$$E_m = E_\mu^2 / \left(\frac{E_\mu + m_e c^2}{2m_e} \right)$$

The lines drawn in the Figures 1 and 2 are the theoretical results calculated after the Bhabha theory. The experimental data for copper target agree well with the theoretical values in figure 1 for different muon momentum regions.

The calculated knock-on electron cross sections of lead target lie appreciably above the experimental results (figure 1) in the three muon energy regions 0.7, 1.1 and 1.6 GeV for small energy transfer in the electron energy range 10-56 MeV, 10-121 MeV and 10-231 MeV, respectively.

In figure 2 the agreement between the experimental results and theoretical ones is not satisfactory for transfer energy $E = 15-60$ MeV but for $E = 60-150$

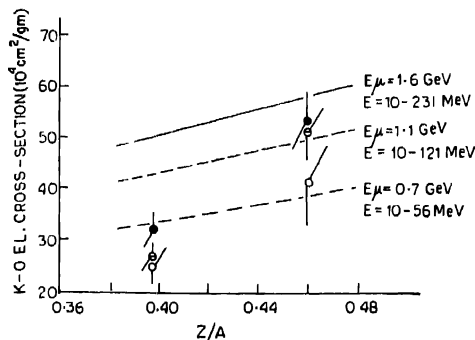


Fig. 1 The knock-on electron cross section per $g\text{-cm}^{-2}$ has been plotted as a function of Z/A of the target material along with the calculated results from Bhabha theory (lines). Data—O, ◐, ●, are the experimental knock-on electron cross section at muon energies $E_\mu = 0.7, 1.1$ and 1.6 GeV for electron energy ranges $10-56$ MeV; $10-121$ MeV and $10-231$ MeV, respectively (Bhattacharyya & Sen Gupta 1969; Bhattacharyya 1973)

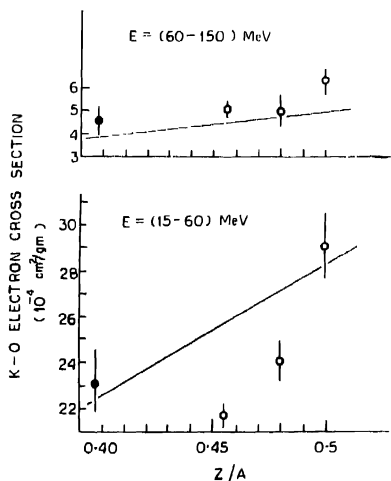


Fig. 2 Comparison of the Z/A dependence of knock-on electron cross section after Stoker *et al* (1963) in lead and Das (1966) in carbon, aluminum, and copper with the calculated values after the theory of Bhabha (1938). Experimental data: ● Stoker *et al* (1963); O Das (1966). The lines drawn in the figures represent the theoretical results.

MeV range the agreement with the theory is satisfactory, which proves the expected Z/A dependence of knock-on electron cross section is in agreement with the experimental results in the region of high energy transfers. In the other regions of energy transfer (E) a large deviation as predicted by Bhabha theory is clearly evident from figures 1 and 2. The experimental data of Bhattacharyya & Sen Gupta (1969) and Bhattacharyya (1973) for energy transfers 10-56 MeV, 10-121 MeV and 10-231 MeV show a strong dependence of knock-on production cross section than those expected from Bhabha theory. This fact is supported by the results of Das (1966) for low and medium Z elements (figure 2) for electron energy transfer 15-60 MeV. The sharp dependence of knock-on electron cross section is not supported by the theory for low energy transfers. On the other hand for electron energy transfer at rather higher energy viz., 60-150 MeV the theory is supported by the experimental results.

Figure 3 shows the comparison of the theoretical cross sections for knock-on electron production by muons with the experimental data of different authors for various energy transfers. The results of Derry & Neddermeyer (1961), Kearney

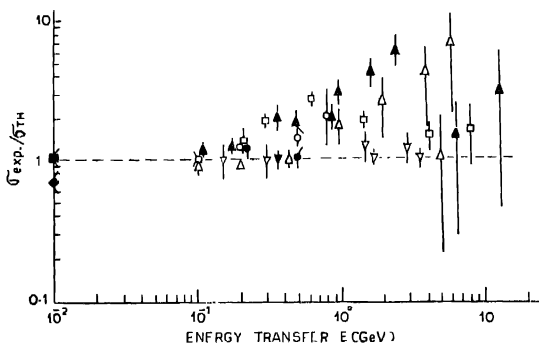


Fig. 3. The ratio of the experimental knock-on electron cross section to the theoretical knock-on electron cross section σ_{exp}/σ_{th} at different electron energy transfer E . Experimental data: ■ Bhattacharyya & Sen Gupta (1969); ■ Bhattacharyya (1973); □ Allkofer *et al* (1971); △ Derry & Neddermeyer (1961); ○ Chaudhuri & Sinha (1965); ▽ Backenstoss *et al* (1963); ● Roe & Ozaki (1959); ▲ Kearney & Hazen (1965); ▽ Kirk & Neddermeyer (1968).

& Hazen (1965), Chaudhuri & Sinha (1965) and Allkofer *et al* (1971) are underestimated by the Bhabha theory for energy transfer above 500 MeV. But the theoretical results are in accord with the measured values for transfer energy above 2 GeV in case of Derry & Neddermeyer (1961), Allkofer *et al* (1971) and the accelerator data of Backenstoss *et al* (1963). A deviation of our data (Bhattacharyya

& Sen Gupta 1969) is observed in case of lead target. But the data for copper target (Bhattacharyya 1973) agrees with the theoretical results within the limits of statistical fluctuations for muon energy around 1.1 GeV.

CONCLUSION

The present study of the experimental data suggests a dependence of knock-on electron cross section on the Z/A of the target material. This fact is supported by the Bhabha theory for electron energy transfer range 60-160 MeV.

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